

# Precise Robotic Orthopaedic Fixation

## Summary

We propose a Precise Robotic Orthopaedic Fixation (PROF) device to help surgeons significantly improve precision during orthopaedic fixation procedures. PROF will combine the use of an automatic image registration and calibration system with a set of simultaneously actuated, computer-controlled distractors for accurate positioning and alignment of bone. PROF will enable the surgeon to precisely specify bone motion to micron-level accuracy in position and milliradian-level accuracy in orientation in all possible degrees of freedom. As shown in the concept illustration in Figure 1, relative positioning of the fixation frames along and orientating about X (red), Y (green) and Z (blue) axes are possible with six actuated distractors arranged in a Gough-Stewart<sup>1</sup> configuration.

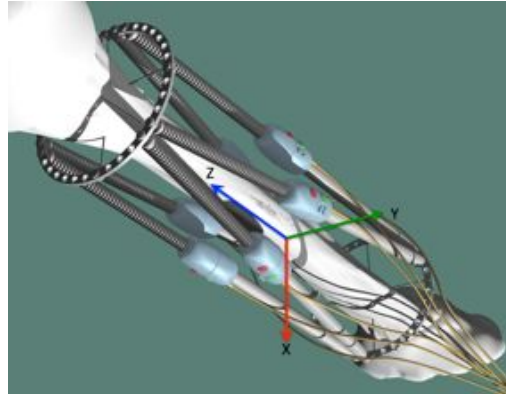


Figure 1 PROF concept installed on a fractured bone.

Precise bone alignment during orthopaedic fixation is essential for bone growth and healing, and successful physical rehabilitation. The current practice with external fixation devices is to sequentially, manually set distractor lengths to achieve the desired bone position. This process is iterative, time-consuming and imprecise because distractor length is related to bone position by complex, non-linear geometric equations. In addition, the typical use of fewer than six distractors arranged in a relatively parallel configuration (Figure 2) limits the relative positioning capability to linear motion and, depending on the configuration, rotation about one or two axes.



Figure 2 External fixation for a fractured tibia.

**Impact of innovation** – With PROF, the surgeon will be able to specify desired relative bone motion along and about the X, Y and Z-axes of a reference Cartesian frame at the fracture site using a three-dimensional computer model that is automatically generated by a registration and calibration procedure. The three dimensional (3D) model will be generated using radiological images of the bone and the installed PROF frame. Desired bone motions specified at the fracture site by the surgeon on a high-fidelity model on a computer display will be converted to corresponding distractor length changes that are automatically applied under computer-control to the distractors. The additional advantage gained with this system is the ability to specify rates of relative bone motion.

Three key technology capabilities to be developed in this effort are: 1) actuated distractors, 2) a registration and calibration algorithm, and 3) a surgical planning program to convert surgeon-specified motion in a Cartesian frame at the fracture site into corresponding distractor lengths.

**1) Actuated Distractor** – The concept design for an actuated distractor is illustrated in Figure 3. The distractor has a base shaft that attaches to one frame of PROF through a gimbal. Within its



body is a motor and sensors to drive a screw linearly to control the distractor length. The screw attaches at the opposite frame in PROF also through a gimbal that also allows

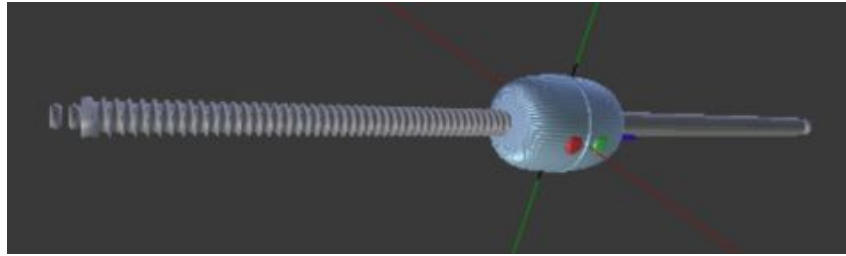


Figure 3 Actuated distractor concept.

free rotational motion about the axis of the screw. Button switches on the distractor body are used to manually extend or reduce its length. The distractor length is also controllable from a computer using signals and power supplied through a cable. Signals from sensors on the distractor that measure its absolute length and its axial force are communicated to the computer also through its cable. Changing the lengths of the base shaft and screw can change the range of motion of the distractor. Six actuated distractors will be needed to control the six degrees of relative motion between the two frames in PROF. A quick connect/disconnect mechanism will be used at the end of each distractor to install or remove it from the fixation frame.

2) Registration and calibration - An important enabling technology for the success of this concept is a process to generate an accurate 3D geometric model of the bone fracture and the locations of the fixation frames with respect to the fracture. The solution proposed is to install the fixation frames on the respective bone elements then image the limb from at least 3 different viewpoints. A software algorithm will process the images to automatically identify fiducials on the frames to register (in scale and 3D location) and calibrate a geometric model to the physical configuration. This procedure may be repeated during the fixation process after the distractors are installed.

3) Surgical planning and motion control – The surgical planning software package to be developed will 1) recommend locations on the respective frames for installation of the distractors, 2) allow the surgeon to articulate the bone fragments in the 3D geometric model to preview alternate fixation motions, 3) provide an interface for the surgeon to specify the desired spatial bone motion, and 4) control PROF to execute the motion at the specified rates while being monitored by the surgeon. Forces exerted during the process will be displayed and will provide the surgeon with an added source of information for monitoring fixation progress.

First introduced in the early and mid-20<sup>th</sup> century, external fixators have become a mainstream approach for the treatment of orthopaedic pathologies<sup>2</sup>. They have been used for many musculoskeletal problems including bone reconstruction, fracture stabilization and treatment of deformities. External fixators are easier to apply and can be manipulated after surgery when compared to internal plates and implants. They offer greater strength and stability, and less interference with soft tissue. However, the application of external fixators is labor intensive<sup>2</sup>. Malunion of bone, increased healing times, and long-term impairment of function are some of the problems resulting from lack of precision in bone alignment with external fixators<sup>3</sup>.

PROF overcomes the deficiencies in external fixation by combining a bone imaging and modeling system to sense and display bone position to the surgeon with a bone positioning system to enable the surgeon to precisely align the bone. The innovation proposed is a unique combination of technologies from a number of areas of robotics. The structural configuration of distractors to form PROF is the Gough-Stewart parallel manipulator<sup>1</sup> that has been studied

widely in the robotics literature. Generalized kinematic algorithms for the control of these robots are well understood. The actuated distractor will incorporate standard sensors that are used to measure position and force on robot joints. Precision control of the motors to drive the distractors will be performed using commercial multi-axes motion control boards that are ubiquitous and relatively inexpensive. While multi-view reconstruction for the generation of 3D models from images is well developed<sup>4</sup>, the challenge in the development of PROF will be to work with the resolution limits and occlusions in images in orthopaedic surgery.

## References

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